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A PULSE REACTOR RADIATION DETECTION SYSTEM USING AN ON-LINE COMPUTER

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
Defense Nuclear Agency
Bethesda, Maryland

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A PULSE REACTOR RADIATION DETECTION SYSTEM USING AN ON-LINE COMPUTER

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FOREWORD
(Nontechnical summary)

Numerous nuclear reactors have been built throughout the world with the capability of safely experiencing, on a routine basis, self-limiting nuclear power excursions. With these reactors, various parameters are of operational and research interest during these power pulses. The power excursions from the reactors occur over such short time intervals and over such large ranges in magnitude that accurate monitoring of the radiations from these excursions is often extremely difficult.

The radiobiology experimentalists, the radiological physicists and the reactor programmer at AFRRI frequently need to know both the total magnitudes and time-dependent variations of various pulse parameters during and after the pulse. A monitoring system using radiation sensors, high gain amplifiers and an SDS 920 computer has been developed which provides a precision to 5 percent (exclusive of the detectors) over a range of sensitivity of six decades. This system is used to provide a time-dependent determination of parameters of interest such as reactor power and energy, relative neutron and gamma ray flux densities (if the spectra remain constant), and neutron and gamma ray tissue kerma rates. The system has been used for the determination of TRIGA reactor performance characteristics during pulse operations of importance in defining and controlling the radiation fields of concern to radiobiology research. For example, with this system the relative contributions of the residual gamma ray and neutron fields after the pulse to the total radiation exposure from the TRIGA reactor pulse have been determined. Details of these and other reactor performance measurements are reported elsewhere.

ABSTRACT

A pulse reactor radiation detection system is described. The system uses an on-line Scientific Data Systems (SDS) 920 computer, coupled through an analog to digital converting interface, to record and retain the response data for various radiation detectors. Results of typical measurements are presented. An overall range of sensitivity of 10^6 is possible with a precision to within about 5 percent (exclusive of the detectors) for determining relative reactor power, neutron and gamma ray flux densities (if the spectra remain constant), and neutron and gamma ray tissue kerma rates or the time integral of these quantities. This range is achieved using combinations of radiation sensors.

I. INTRODUCTION

Numerous nuclear reactors have been built throughout the world with the capability of safely experiencing, on a routine basis, self-limiting nuclear power excursions. These reactors have been put to use in many research fields. Examples of pulse type nuclear reactors in the United States are SPERT, KEWB, TREAT, TRIGA, PULSTAR, and GODIVA. With these reactors, various time-dependent parameters are of operational or research interest during pulsing. Some of these are reactor power, total energy, fuel temperature, absorbed dose rate, absorbed dose, gamma ray flux density and neutron flux density. The prompt radiation bursts from the reactors occur over such short time intervals and large ranges in magnitude that the time variation of the above-cited quantities associated with the bursts are often extremely difficult to determine.

At the Armed Forces Radiobiology Research Institute (AFRRI), a large portion of the radiobiology research utilizes the TRIGA reactor as the radiation source. Many of the experiments are conducted with the pulse radiation fields (bursts) that may be produced with the reactor. These bursts occur with a time duration on the order of milliseconds and produce rapidly changing radiation intensities during this time. The radiobiology experimentalists, the radiological physicists and the reactor programmer (in planning experiments which are sensitive to the total tissue absorbed dose and the tissue absorbed dose rate) frequently need to know both the total magnitudes and the time-dependent variations of pulse parameters during and after the pulse. Specific examples of when both total and time-dependent information are required are: (radiobiologists) when biological responses from the radiation may be absorbed dose rate dependent or sensitive to relative contributions of neutron and gamma absorbed doses to total dose; (radiological physicists) when the response of dosimetric systems may be dose rate dependent or sensitive to relative contributions of neutron and gamma ray absorbed doses to total dose; (reactor programmer) when control of the radiation output of the reactor immediately after a pulse is desired. An extensive study of the AFRRI-TRIGA reactor radiation pulse was undertaken to provide an understanding of how the properties of the radiation fields vary with time during and immediately following the pulse. Some of the results are reported in the literature.[6-10] The reactor parameters monitored with the radiation detector systems were reactor power and energy, neutron and gamma ray absorbed dose rates, neutron and gamma ray total absorbed dose, and relative neutron and gamma ray flux densities. The desired precision of the measurements was to within 5 percent since it was necessary to know some of the reactor radiation parameters (such as neutron and gamma ray absorbed dose rates) to this precision because biological response differences of this magnitude are being investigated by AFRRI radiobiologists.

A major portion of the effort involved in these measurements was the assembly of the readout portion of the system which would provide data to this precision on the time variation of the parameters. It was desirable that the information be obtained in a digitized form to enable examination immediately after the data are obtained and enable storage for detailed analysis by computer software routines at a later time. The major components associated with the system are the radiation sensors, the amplifier components, the computer interface circuitry, the computer and the software. The purpose of this report is to provide the details of the system.

II. DISCUSSION OF THE PROBLEMS ASSOCIATED WITH PULSE REACTOR MONITORING

For a given radiation field, each detector has a particular response which is quantitatively expressed by a reading of the detector system, i.e., a count rate for a foil or a needle indication on a meter. To interpret this reading in terms of the quantity of interest to the user, it is necessary to calibrate the system. The detector device should be chosen to be compatible to the accuracy with which a given parameter can be measured over the range of magnitude and time of interest in the different environments to be used. Ideally in reactor radiation research and monitoring, one desires to select radiation detectors which (1) are only sensitive to those radiation components that are to be determined or (2) are only sensitive to those radiation components which are proportional to the quantities (such as reactor power) that are to be determined. The following are characteristics of the TRIGA pulse reactor which were considered in the design of the system described in the next section.

The radiation environment produced by a reactor during pulse operation is complex, consisting of several radiation components. The primary radiations observed external to the reactor from fission of the fuel are fast neutrons and prompt gamma rays produced at the time of fission and delayed fission product neutrons and gamma rays produced after fission. These primary radiations interact with the fuel, moderator, reflector and structural material in the reactor to cause energy degradation of the primary radiations and the production of secondary radiations. These include neutron inelastic scatter gamma rays, neutron capture gamma rays, moderated and thermalized neutrons, and Compton scatter gamma rays. In a reactor with a neutron generation lifetime on the order of microseconds to milliseconds, all of the above interaction radiations are produced within the same range of time as the primary radiations. It is evident then that isolation of any one component with radiation sensors is difficult.

Any radiation parameter related to the transient reactor power level will experience a large range of variation in magnitude during a pulse. The initial power of the reactor at AFRRI prior to the pulse is usually procedurally established at 15 watts; however, pulsing can be done from as high as 1 kilowatt. For the largest reactivity insertions used, the peak power is 2600 megawatts. Immediately after the pulse, the slowly varying delayed power tail is observed[8] to be approximately 4 megawatts and declines to about 1 megawatt in 3 seconds.

III. DESCRIPTION OF SYSTEM

Radiation Sensors

Due to the very large range of sensitivity required to monitor most parameters of interest during pulse reactor operations, current type detectors (such as ionization chambers) were chosen in lieu of the various pulse signal types due to their inherent counter dead time losses at high count rate. A readout was required that could directly use an analog current or voltage signal and convert the analog signal to a digital value for immediate examination and further analysis with computer codes. It was desirable in each case that a detector in a fixed geometrical configuration with respect to the reactor be capable of accurate measurement of the pulse variable to be measured over the entire range of values experienced before, during and after the pulse.

The radiation sensors mentioned here are presented simply to provide examples of the type of detectors that may be used to provide information about the reactor pulse environment. By using these sensors it was possible (in some instances by using several sensors whose response ranges overlapped) to monitor time-dependent reactor power and separate neutron and gamma ray tissue kerma rates for the reactor pulses.

Measurement of the total tissue-equivalent kerma rate (neutron tissue kerma rate plus gamma ray tissue kerma rate) as a function of time from the AFRRI-TRIGA pulse was performed employing a 0.05 cm^3 sensitive volume miniature tissue-equivalent ionization chamber. Details of the construction configuration and response of a similar 0.01 cm^3 sensitive volume chamber are presented in an AFRRI Technical Note.[5]

The separate neutron and gamma ray kerma components of the mixed radiation field from the AFRRI-TRIGA reactor were measured employing two 50 cm^3 ionization chambers, one of tissue-equivalent plastic and the other of graphite. Tissue-equivalent gas and CO_2 gas were used in the tissue-equivalent and graphite chambers, respectively. Details regarding these chambers and the separation of neutron and gamma kerma rates may be found in an AFRRI Contract Report[13] and the National Committee on Radiation Protection and Measurements Report 25.[12] Since these comparatively large chambers exhibit recombination effects at the kerma rates produced even at 1 megawatt steady-state reactor power, it was necessary to obtain chamber saturation data for reactor pulses.

Gamma ray and neutron sensitive SEMIRADs (secondary emission radiation detectors) were used to measure relative gamma and neutron fluences in instances where spectra changes did not occur. These detectors consist of evacuated stainless steel or aluminum walled chambers lined with boron-10 (for thermal neutron detectors), lined with depleted uranium or polyethylene (for fast neutron detectors), or unlined (for gamma ray detectors). Further details regarding the response and operation of these instruments may be found in the literature.[4]

<u>Current-Voltage Amplifiers and Integrators</u>

The currents from the detectors were provided through low impedance coaxial cable to the inputs of high precision, high gain amplifiers. The amplifiers used were Philbrick Researchers Corporation Model P85A solid-state plug-in units with a Philbrick Researchers Corporation operational manifold. Other commercial amplifiers of comparable precision are available. The resistors and capacitors used in measurements were accurate with respect to their rated values to within 1 percent. When the operational amplifier units were used solely for electronic gain, the gain was controlled in the conventional way by using selected values of input and feedback resistors. The lowest input resistor used was 10 kilohms and the highest feedback resistor used was 2 megohms thus providing a maximum gain of 200 per amplifier stage. In some instances, two stages were used with a total gain of as much as 4×10^4. This was found to be necessary in the low level measurements with the miniature ionization chamber. In cases where excessive cable noise was observed with these high gains, an electronic filter was obtained by using a 0.04 microfarad capacitor between the signal lead and ground. This resulted in reducing the high frequency noise while producing negligible distortion of the signal even for the maximum TRIGA pulse observed (3.21 x β). The output from the Philbrick high gain amplifiers is a voltage signal. The voltage signal is proportional to neutron and/or gamma ray flux density or the kerma rate depending on which detector is used. Figure 1A shows the schematic diagram for linear output of detector responses. The detector responses may be also obtained as a logarithmic output with the circuit shown in Figure 1C.

When total kermas or fluences (neutron and/or gamma) were desired, integrating circuits were assembled. A schematic diagram of such a circuit is shown in Figure 1B. The Zener diodes provide protection of the amplifiers from high voltage levels when high gains are used.

AFRRI Data Acquisition System Circuitry

The AFRRI Data Acquisition System (DAS) is built around a Scientific Data Systems (SDS) 920 computer with 16384 words of 24-bit memory and 48 priority interrupt channels. Many of the existing components to the AFRRI DAS are the same as discussed in the literature earlier.[2,11]

Control of input devices is generally by any of three means; manual control, experimental device control, or by control pulses from the computer. Computer control pulses are obtained by decoding 256 of the energize output medium (EOM) control pulses from the computer. (The decoded pulses which are used in various portions of the interface are +8 V in amplitude from ground reference and are 4.6 μsec wide.)

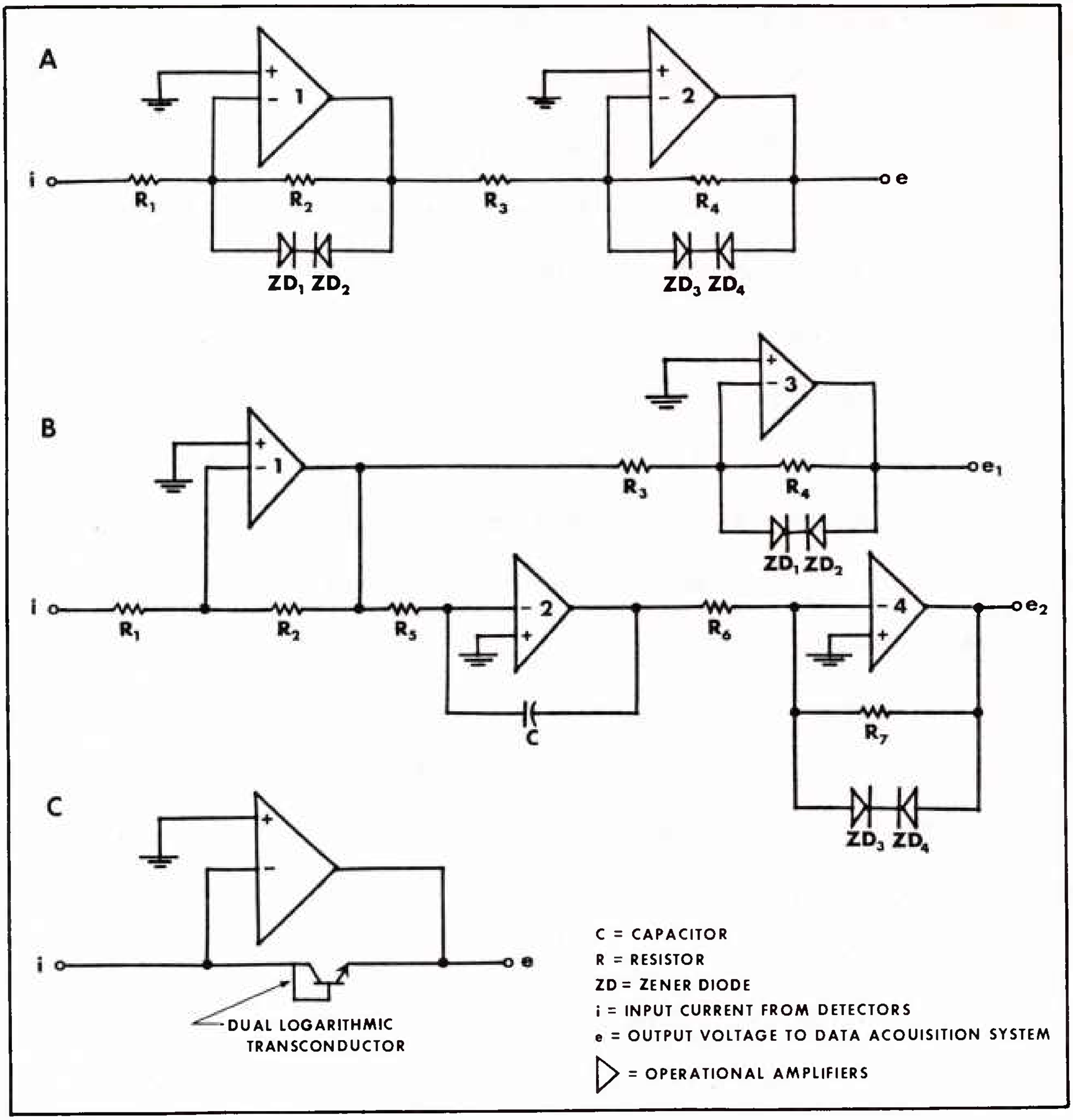

Figure 1. Schematic diagrams of operational amplifier systems for (A) linear output, (B) linear and integrated linear output and (C) logarithmic output

When an input device is ready to transfer information to the computer, a priority interrupt signal unique to that device is initiated. This transfers the computer program execution to an associated subroutine which reads the information into the computer through the multiplex register unit. The priority interrupt signals from the various input devices are connected to the computer through a patch-panel to allow the priority assignments of different devices to be readily changed. This flexibility in priority assignment is also contained in the software program.

For all input devices, a read-in of the input signal can also be initiated by program control without a priority interrupt being executed.

The interface consists of: an EOM decoder, input multiplex register, analog to digital converter with eight input channels, four scaler units, eight pulse height analyzers, program selector board, three dimensional oscilloscope controls and group enable gates. (The interface also contains two logic panels which are not connected to the computer or input units. These logic panels contain amplifiers, switches, gates, level shifters, detectors, inverters, pulse generators, etc. which allow the user to obtain maximum flexibility from the DAS.[3])

The interface circuit used, for the pulse reactor monitoring system described in this report, to acquire the analog signals for computer storage is shown in Figure 2. The data sampling rate is variable and may be selected to provide sufficient data points in the time domain of interest. Two channels of data may be sampled simultaneously and held in the sample and hold units until the computer can accept the information as directed by the clock. The minimum sampling time for the computer is 0.25 milliseconds, consequently for two channels of data the minimum time between data points is 0.50 milliseconds. For reactor pulse measurements, the trigger signal to start the data storage is provided from the transient rod off bottom microswitch located on the reactor carriage. The software program for the SDS 920 provides for storage of 512 data points in each of two data channels.

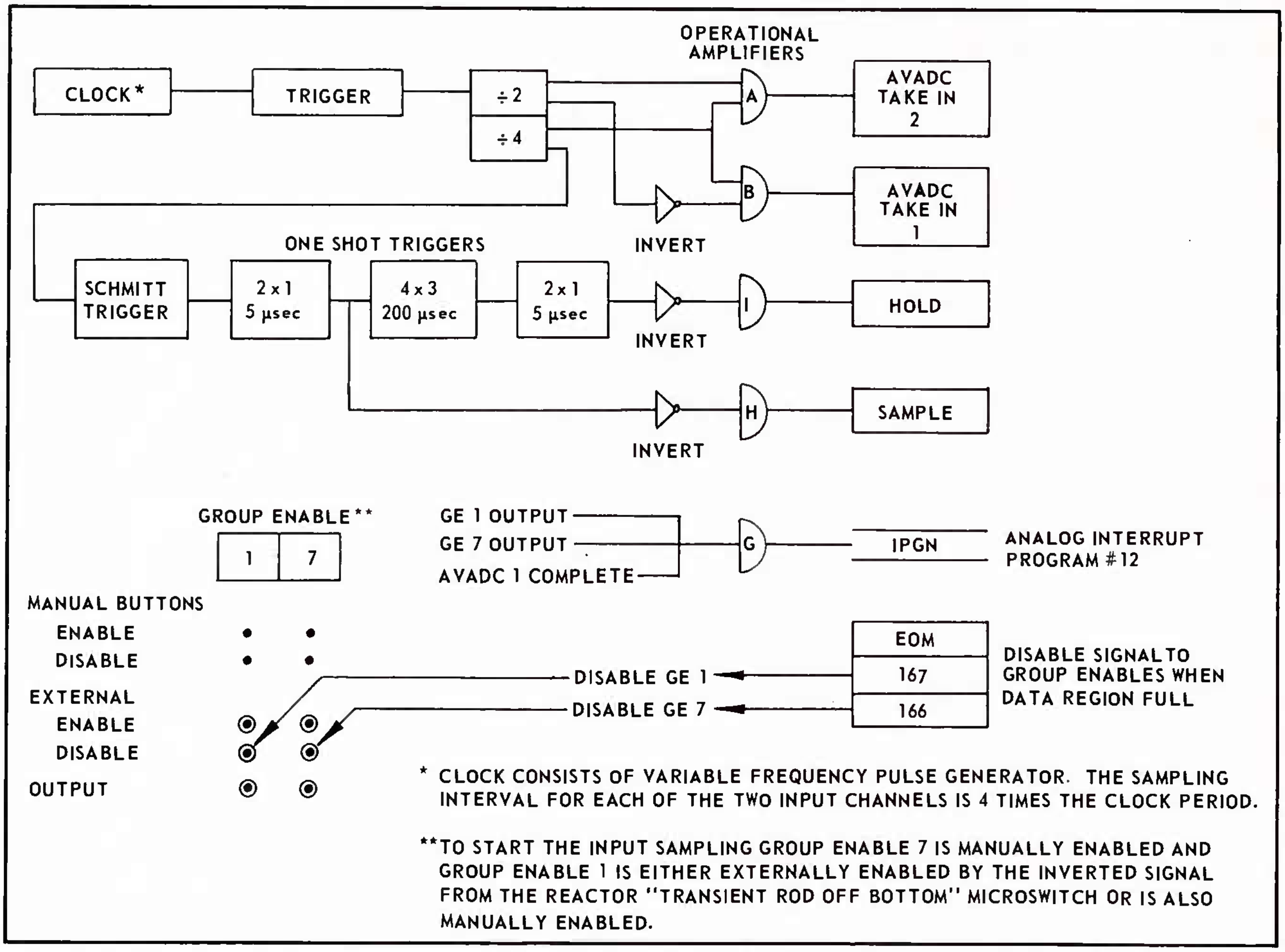

Figure 2. AFRRI Data Acquisition System interface to SDS 920 digital computer for on-line reactor pulse monitoring

Computer Software Programs

The basic program for the system is the Remote On-Line Monitor and Experiment Operator (ROMEO) master program. This program and other subroutines are loaded into the central processor region of the DAS. This thus provides the logic connection between the computer and the interface. Table I lists the programs in the order in which they are loaded into the central processor. The data obtained in the computer memory may be read out in typed form or displayed on an oscilloscope. In instances where further analysis or processing of the data is desired the data may be stored on magnetic tape or punched on paper tape. A primary memory region accepts the 1024 data points from the interface and a "dummy" memory region enables these data to be held for inspection while a second set of reactor pulse data is being acquired in the primary memory region. These operations are controlled by the program selector board (PSB) portion of the interface. Figure 3 provides PSB dial settings and operations for reactor pulse measurements. Write-ups of the ROMEO software programs are contained in an unpublished AFRRI document.[1]

Table I. Programs Loaded into the Central Processor Subsystem of the Data Acquisition System

Program	Function
ROMEO Master Abridged dated 13 December 1967	Master Control
BPHZ	Board Program - Clear Busy Flags (BPØØ75)
BPJX	Board Program - 512 Channel Sequester (BPØØ22)
BPSA	Board Program - Scope No. 1 (BPØØØØ)
BPRA	Board Program - Paper Taper (BPØØ11)
BPQC	Board Program - Magnetic Tape (BPØØØ4)
BPTF	Board Program - Type Data (BPØØ14)
BPLB	Board Program - Clear Data (BPØØØ7)
IPGN	Interrupt Program - Analog Input (IPØØ12)

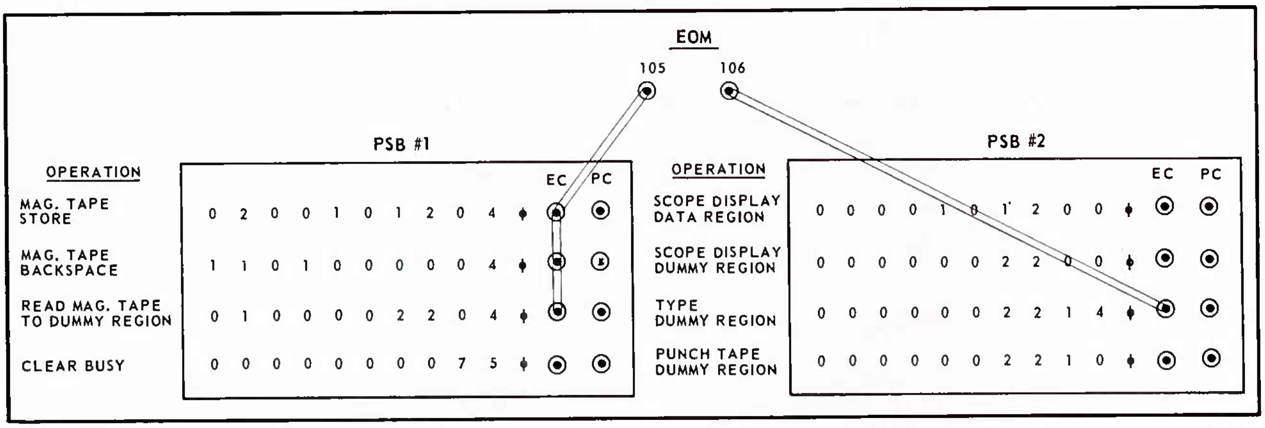

Figure 3. Program selector boards for control of computer operations

IV. PRECISION OF SYSTEM AND TYPICAL RESULTS

Precision

The precision of the overall system in measuring currents over the range encountered (from about 10^{-10} to 10^{-2} amperes when using a combination of detector sensors) depends upon the precision of the individual components. It therefore depends upon (1) the signal attenuation and noise pickup in the approximately 150 feet of low noise cable used to transmit the signals from the reactor exposure rooms to the computer room, (2) the linearity of the amplifiers and accuracy of the input and feedback resistors, (3) the precision of the analog voltage analog to digital converters (AVADC) and sample and hold units in the DAS (computer interface) and (4) the internal noise level of this computer interface. The amplifiers are specified by the manufacturer to be linear to less than 1 percent. The resistors used are claimed to be accurate to 1 percent of their quoted values. The linearity of the analog to digital converters and sample and hold units in sampling the voltage input signals from the amplifiers was tested using a Dial-A-Volt voltage source manufactured by General Resistance, Inc. This unit is accurate as a voltage supply to five significant digits as long as overloading does not occur. Care was taken to prevent this. The calibration of the DAS and SDS 920 computer for voltage inputs showed that this part of the overall system was accurate to three significant digits of computer memory data. The uncertainty in the fourth digit was caused by internal noise and constant voltage levels from the DAS and computer. The total system including the cables, amplifiers and the computer was tested using a Model 261 picoampere source manufactured by Keithley Instruments, Inc. This unit supplies, under nonoverload conditions, a current source output from 10^{-12}

to 10^{-4} amperes which is accurate to within $\pm$ 0.5 percent over this range. The linearity of the overall system was tested at intervals of 1, 2, and 5 units of each decade of current supply through the range from 10^{-10} to 10^{-4} amperes by supplying the currents at the exposure room cable connections. A linearity to within 5 percent was obtained. The primary difficulties at low current (thus high amplifier gain) values were in nulling the amplifiers against error signals from the input and chassis noise levels.

Intercalibration of the current outputs of the various detectors was performed in the radiation fields at levels where the chambers were known to exhibit linear, saturated current response.

Typical Results

Results of various measurements performed with this overall system have been presented in the literature.[6-10] We show, as examples, the response rate data obtained with both the linear and logarithmic amplifier circuits and the integrating response circuit. Figure 4 shows the computer oscilloscope display of data obtained with the linear gain amplifier circuit given in Figure 1A. For each of the three displays a factor of 10 difference in feedback resistor (and thus net gain) values was used. Figure 5 provides the display of the data using the logarithmic gain amplifier circuit given in Figure 1C; 1.50, 2.00, 2.50 and 3.21 x β pulses are shown superimposed on the photograph. Figure 6 shows the response rate data from the first 512 data points and superimposed on it the integrated response data from the second 512 data points, using the circuit given in Figure 1B for a 2.00 x β pulse. These data were obtained from a lead shielded ^{10}B SEMIRAD detector which provides (after calibration)

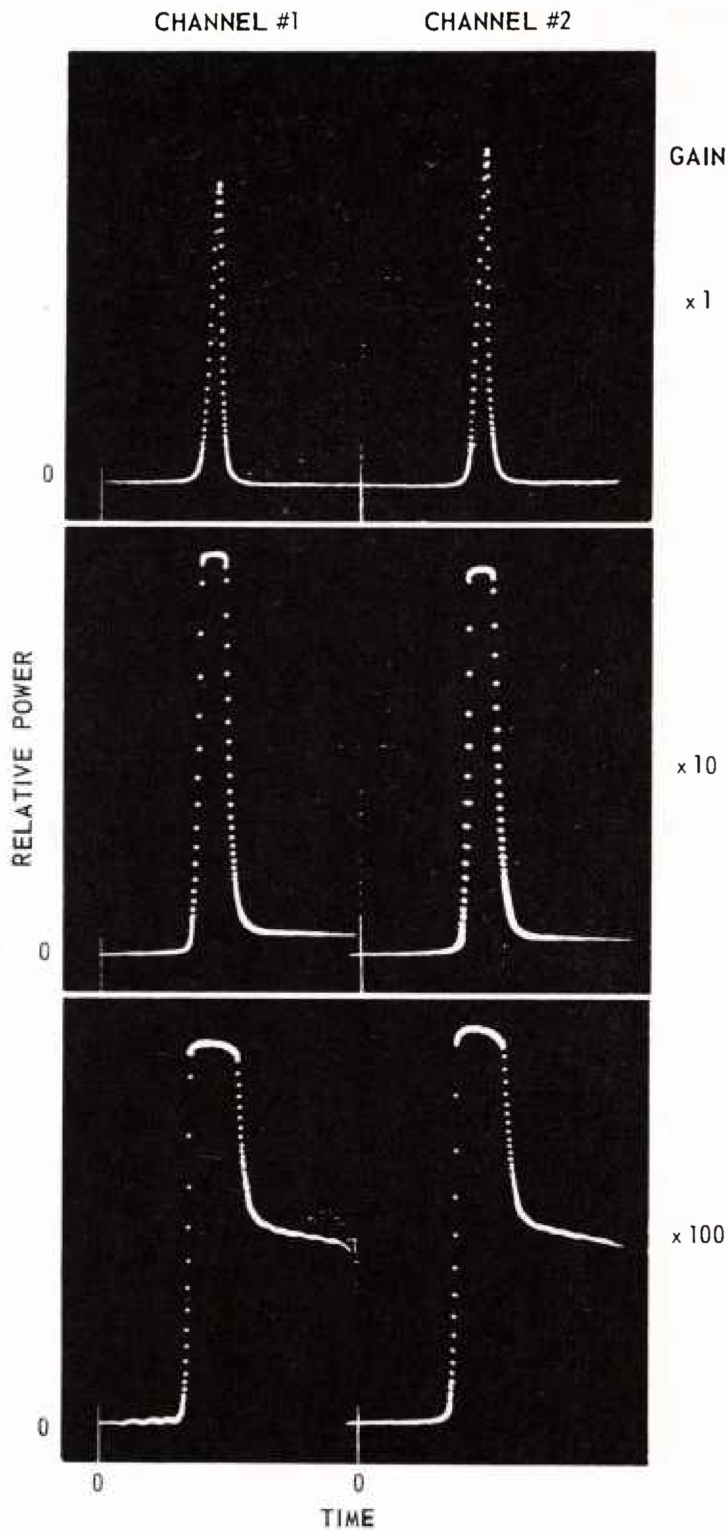

Figure 4. Computer oscilloscope readout of raw data from reactor pulse measurement at three different linear amplifier gains

response proportional to the neutron fluence rate. Reactor power levels (relative to the thermal power calibrations performed by the reactor operating staff) were determined by calibration of the response of the detector for steady-state reactor runs up to 1 megawatt.

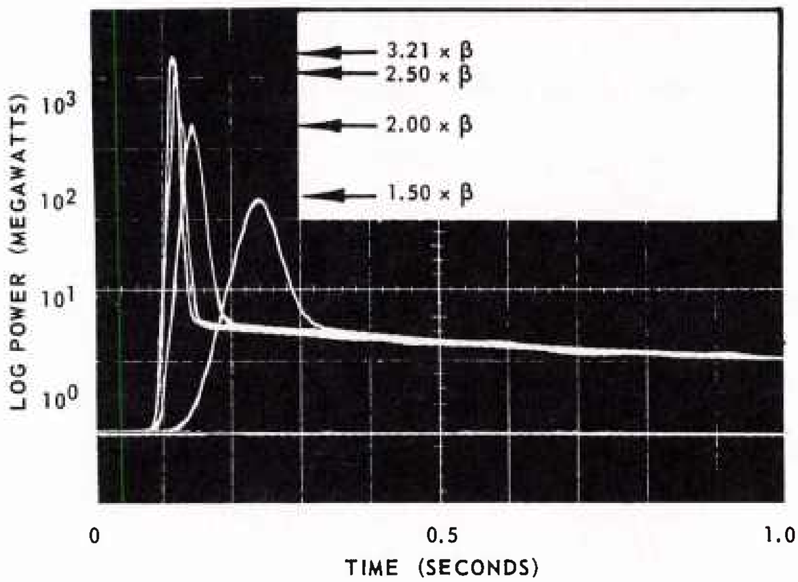

Figure 5. Logarithmic reactor power versus time for 1.50, 2.00, 2.50 and 3.21 x β pulses from the AFRRI-TRIGA reactor as obtained by the on-line computer system

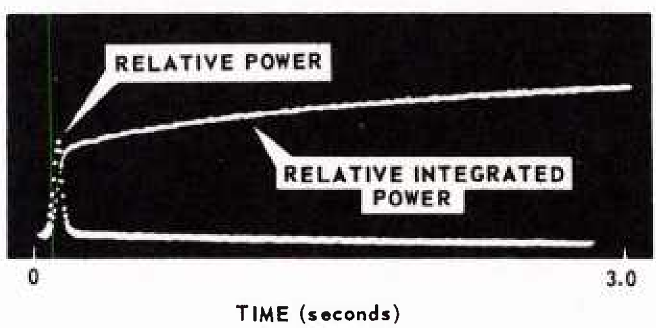

Figure 6. Computer oscilloscope raw data for reactor power and integrated power for 2.00 x β pulse

V. SUMMARY

A precision pulse reactor radiation detection system has been described. The system uses an on-line SDS 920 computer and a data sampling interface as a data acquisition system to record and retain the response data for various radiation detectors. Examples of measurements obtained are presented. An overall range of 10^6 is shown to be possible for currents for neutron and gamma ray detectors. The precision of the system (exclusive of the radiation detectors) is within 5 percent. This range was obtained using a combination of radiation sensors. The minimum time between data points is 0.25 milliseconds (which is established by the limitation of the data acquisition system) for one detector channel and 0.50 milliseconds for two detector channels of simultaneous data. The system therefore should be perfectly adequate for most moderated reactor assemblies but not adequate for fast reactors.

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13. ABSTRACT

A pulse reactor radiation detection system is described. The system uses an on-line Scientific Data Systems (SDS) 920 computer, coupled through an analog to digital converting interface, to record and retain the response data for various radiation detectors. Results of typical measurements are presented. An overall range of sensitivity of 10^6 is possible with a precision to within about 5 percent (exclusive of the detectors) for determining relative reactor power, neutron and gamma ray flux densities (if the spectra remain constant), and neutron and gamma ray tissue kerma rates or the time integral of these quantities. This range is achieved using combinations of radiation sensors.

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